Surrogates in the Seventies

Nuclear Reactions on Unstable Nuclei

and the

Surrogate Reaction Technique

Workshop 2004

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Asilomar

January 12-15, 2004

What are Surrogates?

- Use of Charged Particle Reactions to Simulate Neutron Induced Reactions

Why Surrogates?

- Neutron Measurements are Always Difficult
- Low Beam Intensities Require Thick Targets
- Radioactive Materials ξ Thick Targets
- Reactions on Off Stability Species Needed
  - Astrophysics
  - National Security Programs
  - Nuclear Waste Transmutation

Radiochemical Diagnostics

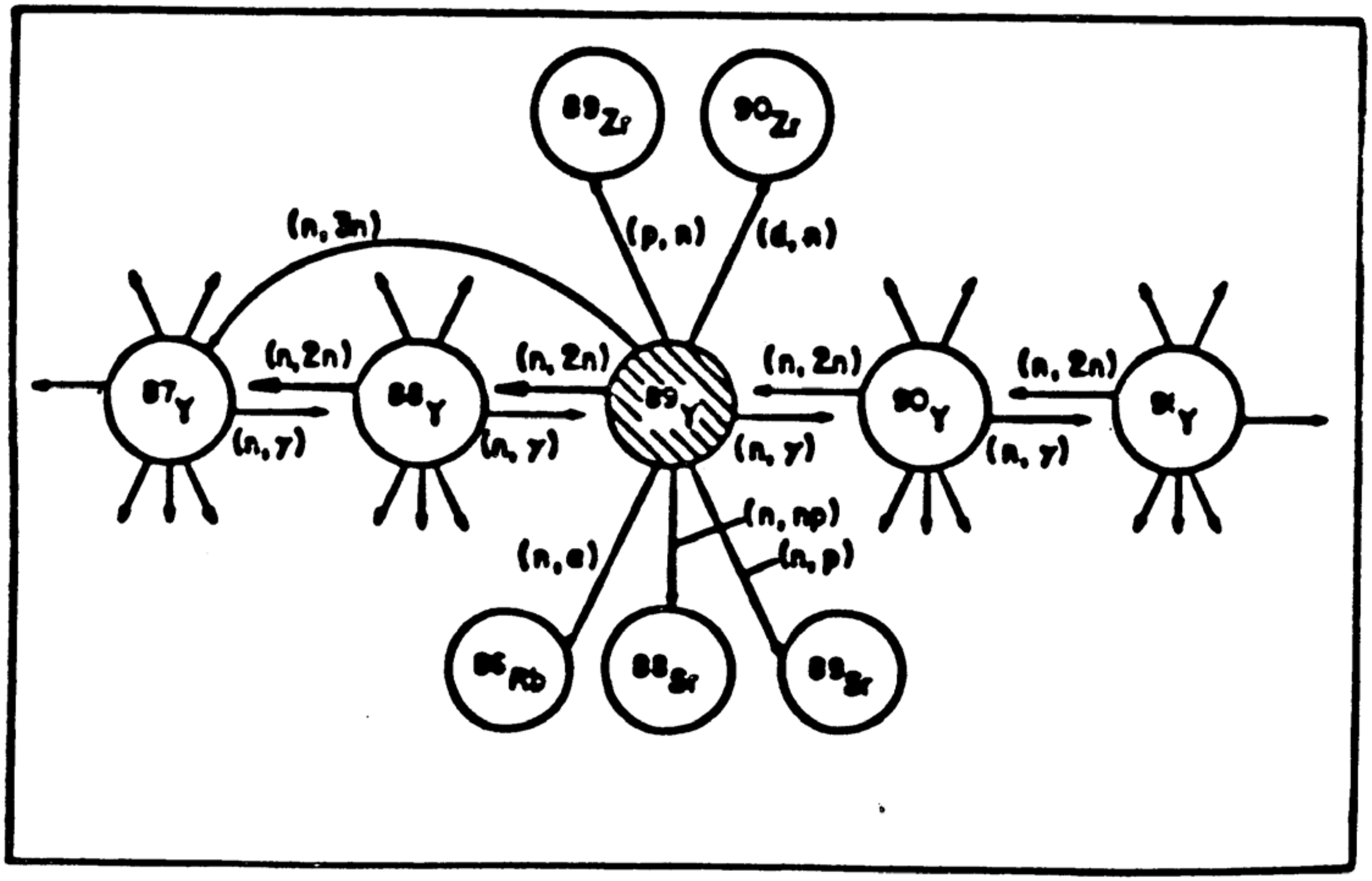
Nuclear Reactions on Specific Elements Loaded in Selected Areas of the Device are used to determine the Performance

The High Fluence Environment of the Device Produces many off Stable Isotopes and Nuclear Reactions on these are of great Importance to Characterise the Test.

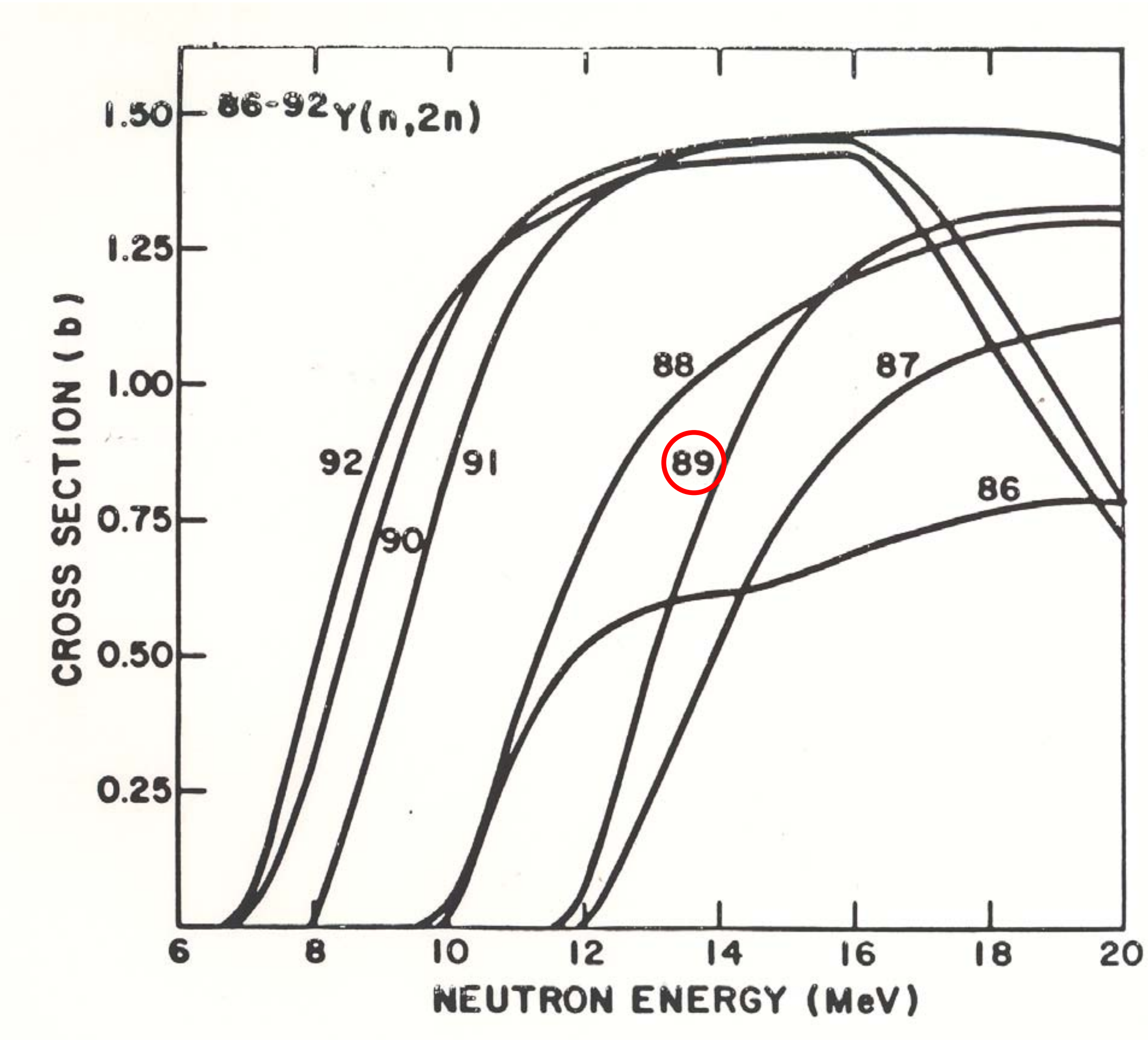
THERE ARE THREE ASPECTS TO THE PROGRAM DESIGNED TO MEET OUR REQUIREMENTS.

- THE MEASUREMENT OF FAST NEUTRON (14-15 MeV) CROSS SECTIONS ON RADIOACTIVE TARGETS.
- THE USE OF CHARGED PARTICLE DIRECT REACTION TECHNIQUES TO SIMULATE n,f, n,p, AND n,α CROSS SECTIONS ON EXOTIC NUCLEI.
- NUCLEAR MODEL CALCULATIONS WHICH INCORPORATE MANY FACETS OF NUCLEAR DATA MEASURED ON STABLE ISOTOPES. THE MODEL IS USED TO CALCULATE NUCLEAR REACTION PROPERTIES OF NON-STABLE ISOTOPES AND PREDICTIONS ARE MODIFIED BY THE EXPERIMENTAL DATA OBTAINED ABOVE IN AN INTERACTIVE PROCESS.

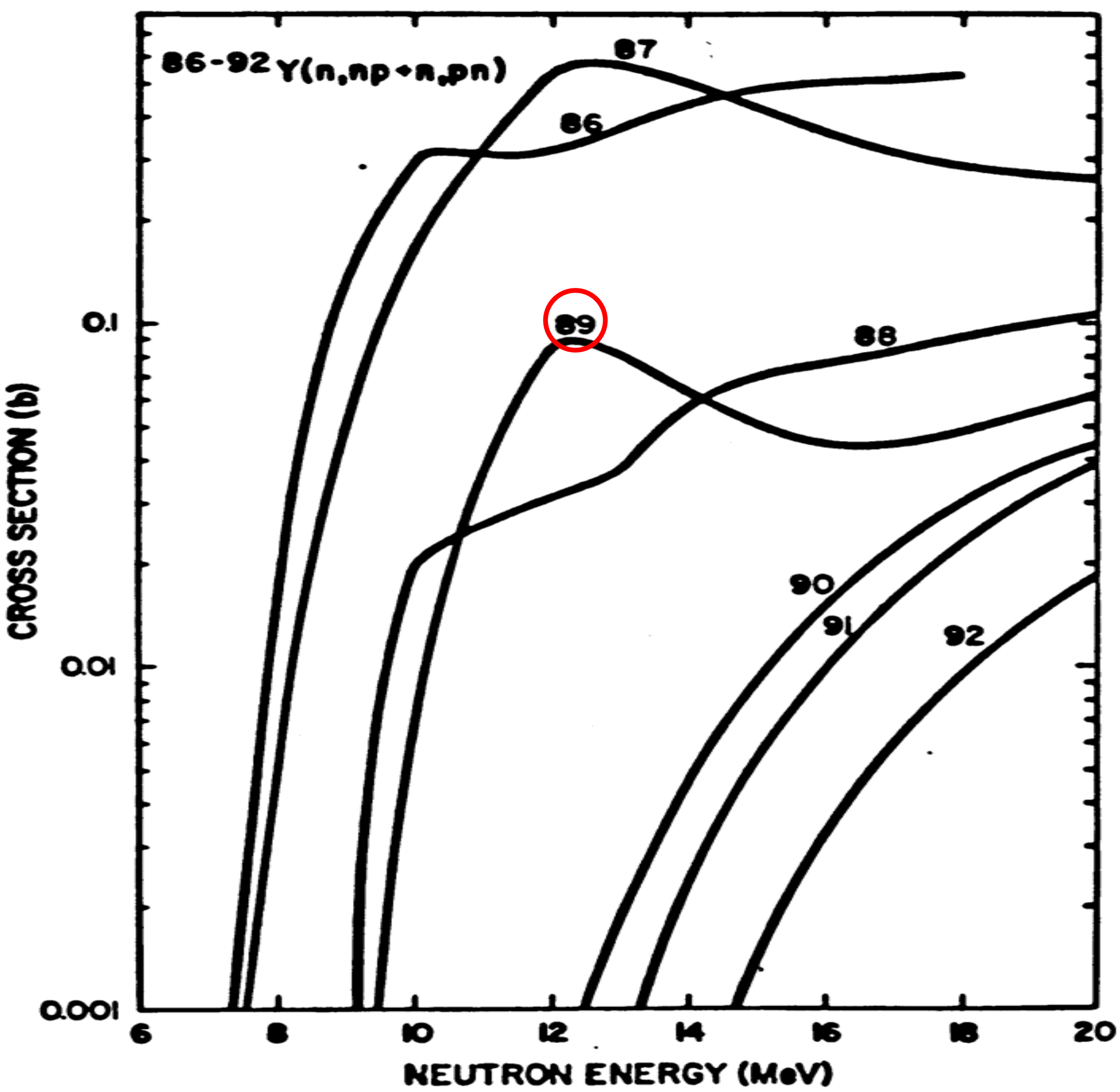
Radchem Reactions on Y



Y(n,2n) Reactions



Y(n,p) Reactions



REPRINTED FROM NBS SP 425 Volumes I and II

Nuclear Cross Sections and Technology

Proceedings of a Conference
Washington, D.C.
March 3-7, 1975

(n,f) CROSS SECTIONS FOR EXOTIC ACTINIDES*

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ABSTRACT

Neutron induced fission cross sections have been obtained for 26 actinide nuclei using (^{3}He,df) and (^{3}He,tf) reactions to determine fission probabilities and then multiplying these values by calculated compound nuclear neutron reaction cross sections. Comparison with existing (n,f) data shows this to be a feasible approach for obtaining reliable estimates for (n,f) cross sections where direct measurements are not possible. Theoretical developments in interpreting fission probability measurements are discussed.

[NUCLEAR REACTIONS Measured P_f $^{230-233}$Pa, ^{231,232}U, $^{233-239}$Np, ^{237,238}Pu, $^{239-243}$Am, $^{241-244}$Cm, ^{248,249}Bk using (^{3}He,df), (^{3}He,tf), E = threshold - ∿12 MeV; deduced $\sigma_{n,f}$.]

NUCLEAR SCIENCE AND ENGINEERING: **72**, 222-229 (1979)

Simulated (n,f) Cross Sections for Exotic Actinide Nuclei

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Received March 12, 1979
Accepted June 14, 1979

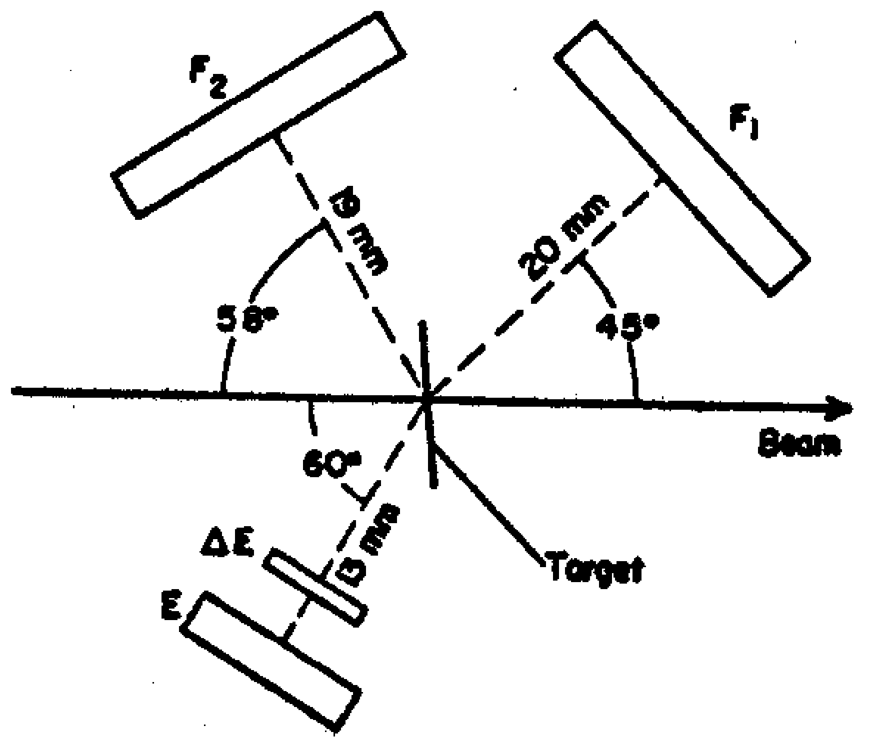
Simulated (n,f) cross sections for E_n = 0.5 to 6 MeV are estimated from fission probabilities obtained in (^{3}He,df) and (^{3}He,tf) studies. Cross sections are presented for 34 isotopes of protactinium, uranium, neptunium, plutonium, americium, curium, berkelium, and einsteinium. Results are compared to direct (n,f) measurements for five cases.

$$P_f \rightarrow \sigma(n,f)$$

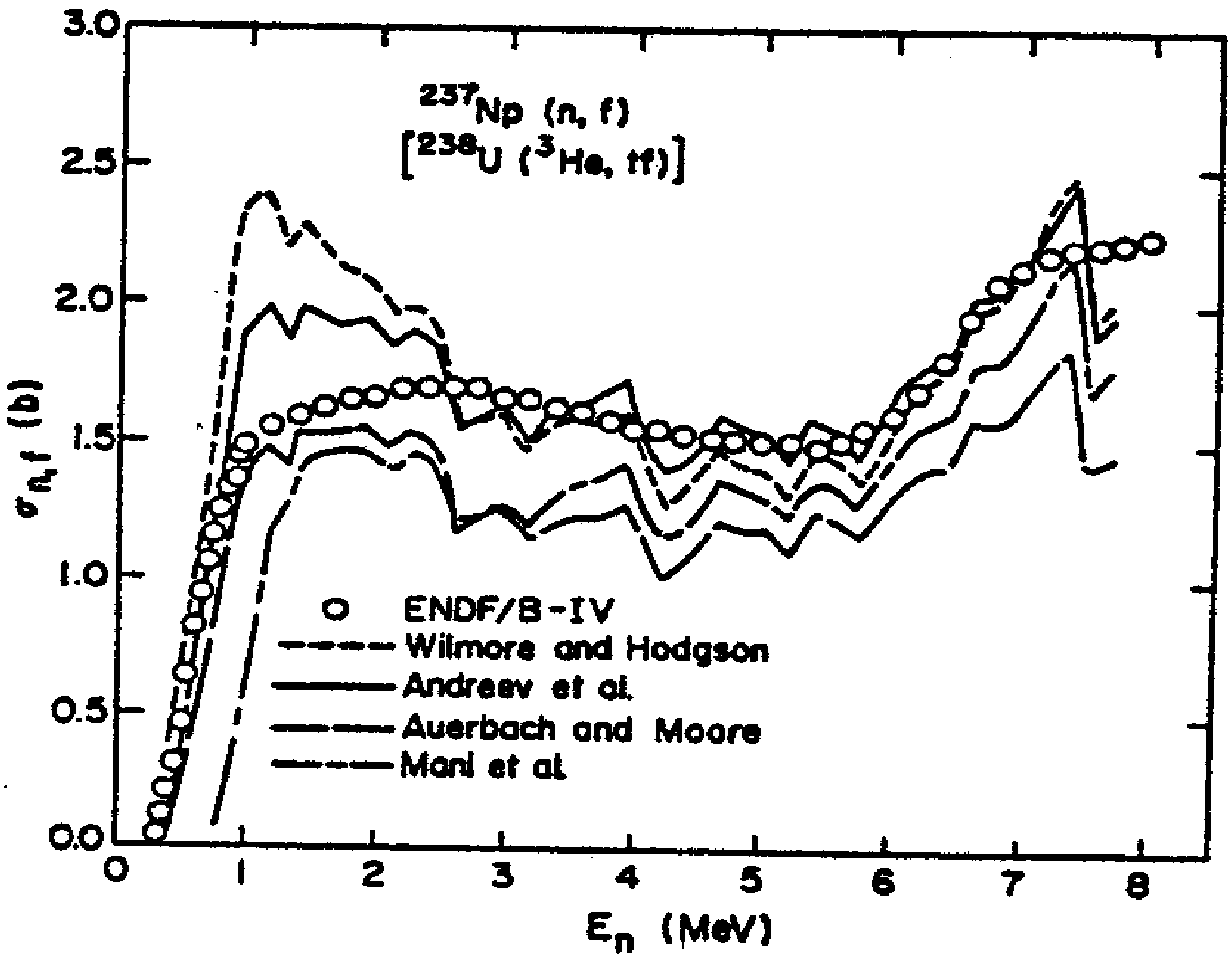
$$P_f(E^*) = \left\langle \frac{\Gamma_f}{\Gamma_f + \Gamma_n + \Gamma_\gamma} \right\rangle_{J\pi} ,$$

$$\sigma_{n,f}(E_n) \approx P_f(E_n + B_n) \cdot \sigma_{\mathrm{CN}}(E_n) ,$$

Experimental Configuration



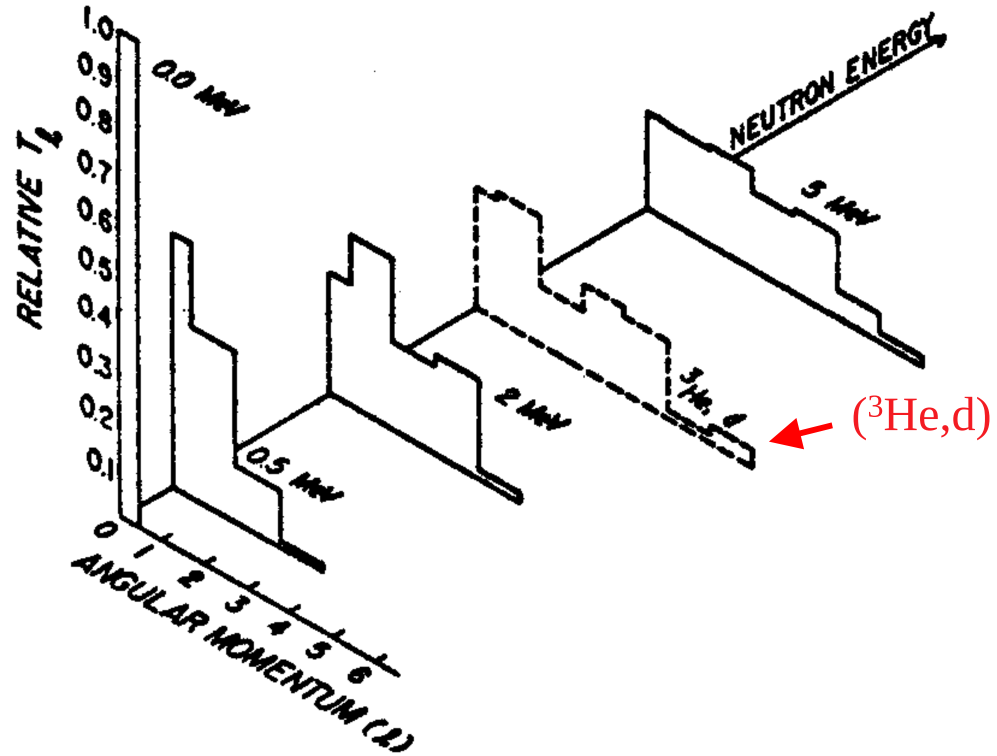
σ_{CN} Choices



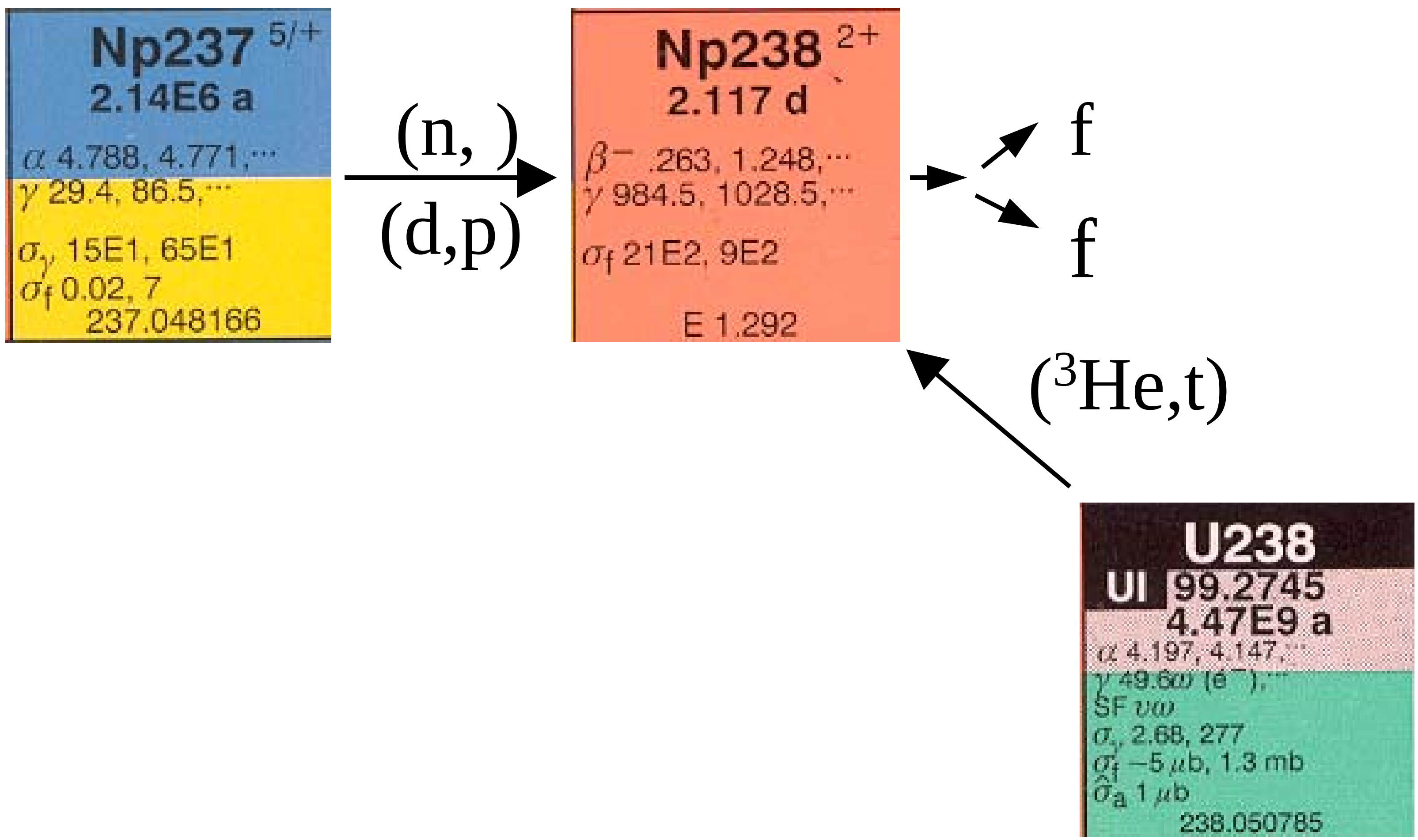
(n,f) Surrogate Eqn

$$\sigma_{n,f}(E_n) = 3.1 \cdot P_f(E_n + B_n)\,\mathrm{b}$$

T_λ Distributions



$^{238}Np^* \rightarrow f$



$^{238}Np^* \rightarrow f$ (0-7 MeV)

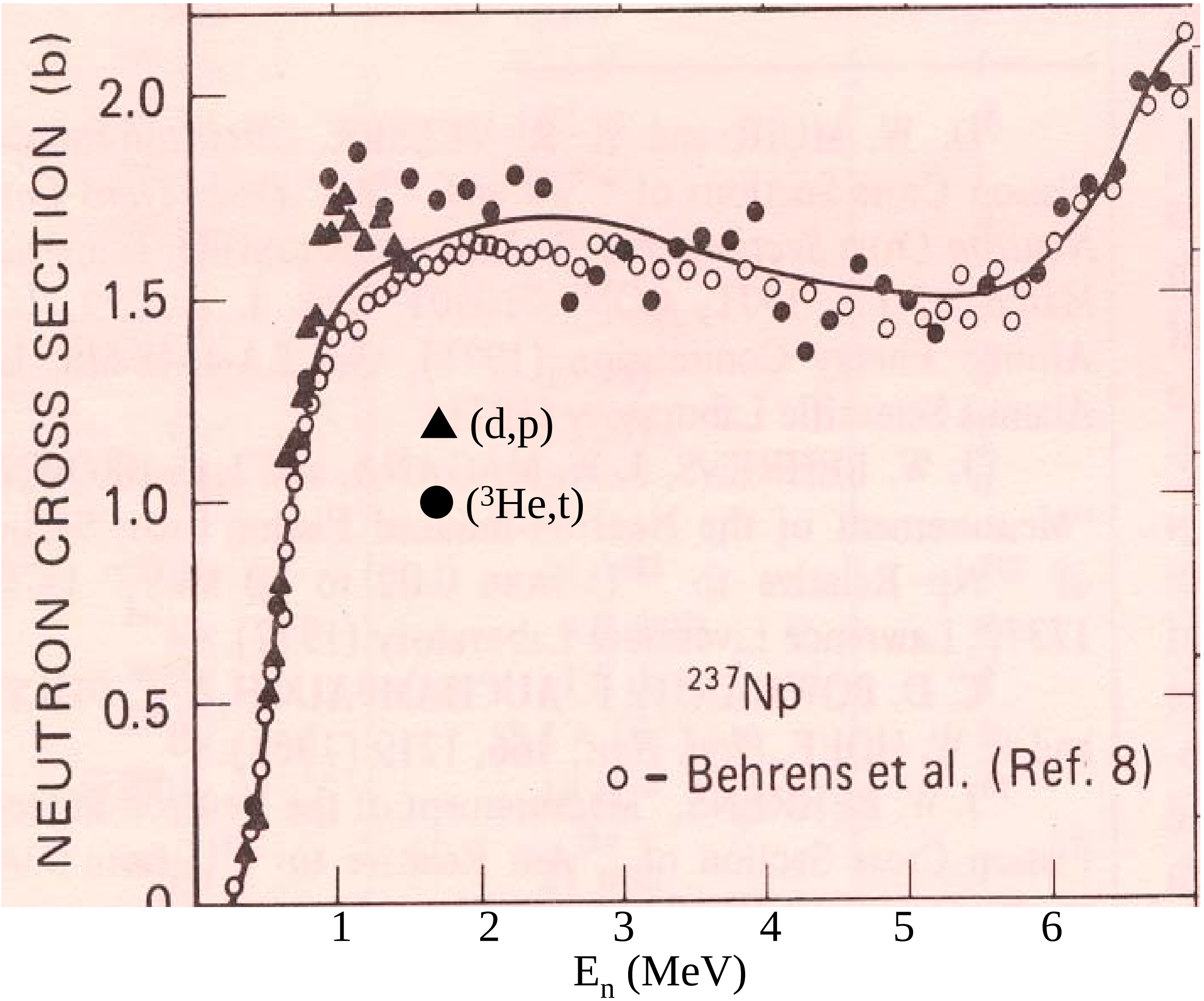


Table I

'Neutron Target'	$t_{1/2}$	Max Energy Neutron (MeV)	Compound Nucleus
^{229}Pa	1.4 d	5.2	^{230}Pa
^{230}Pa	17.4 d	3.7	^{231}Pa
^{231}Pa	3.25×10^{4} y	6.3	^{232}Pa
^{232}Pa	1.32 d	4.4	^{233}Pa
^{230}U	20.8 d	7.0	^{231}U
^{231}U	4.2 d	5.2	^{232}U
^{232}Np	14.7 m	3.0	^{233}Np
^{233}Np	35 m	3.9	^{234}Np
^{234}Np	4.4 d	6.2	^{235}Np
^{235}Np	396. d	6.6	^{236}Np
^{236}Np	1.3×10^{6} y	4.3	^{237}Np
^{237}Np	2.1×10^{6} y	7.7	^{238}Np
^{238}Np	2.12 d	5.2	^{239}Np
^{236}Pu	2.85 y	7.2	^{237}Pu
^{237}Pu	45.6 d	5.6	^{238}Pu
^{238}Am	1.63 h	5.1	^{239}Am
^{239}Am	11.9 h	5.5	^{240}Am
^{240}Am	51. h	3.9	^{241}Am
^{241}Am	433. y	6.8	^{242}Am
^{242}Am	152. y	4.6	^{243}Am
^{240}Cm	26.8 d	6.2	^{241}Cm
^{241}Cm	36. d	4.6	^{242}Cm
^{242}Cm	163. d	7.1	^{243}Cm
^{243}Cm	28. y	5.3	^{244}Cm
^{247}Cm	1.4×10^{3} y	5.9	^{248}Cm
^{247}Bk	18. h	4.2	^{248}Bk

Study of the Feasibility of Simulating (n,α) and (n,p) Cross Sections with Charged Particle Direct Reaction Techniques

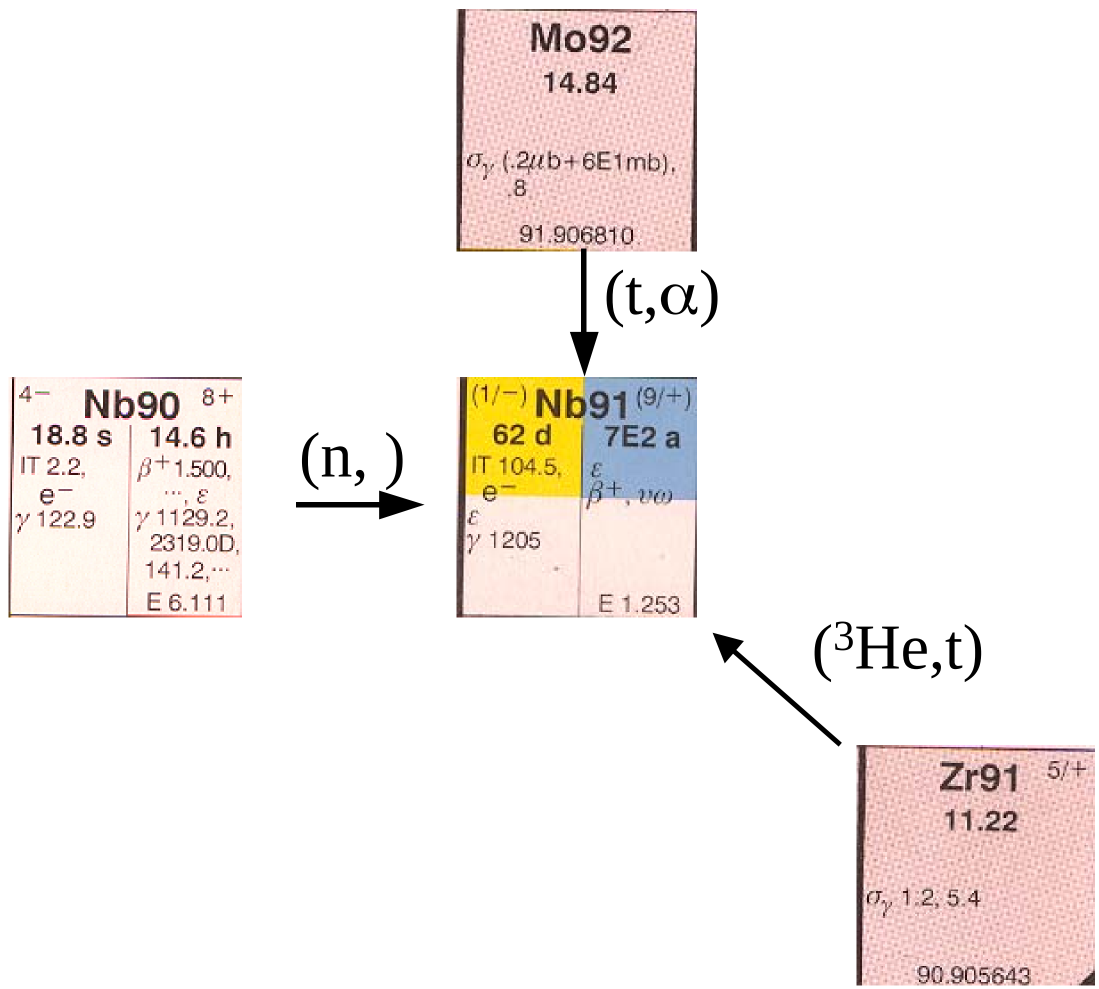
Progress Report

Program Code - W 223

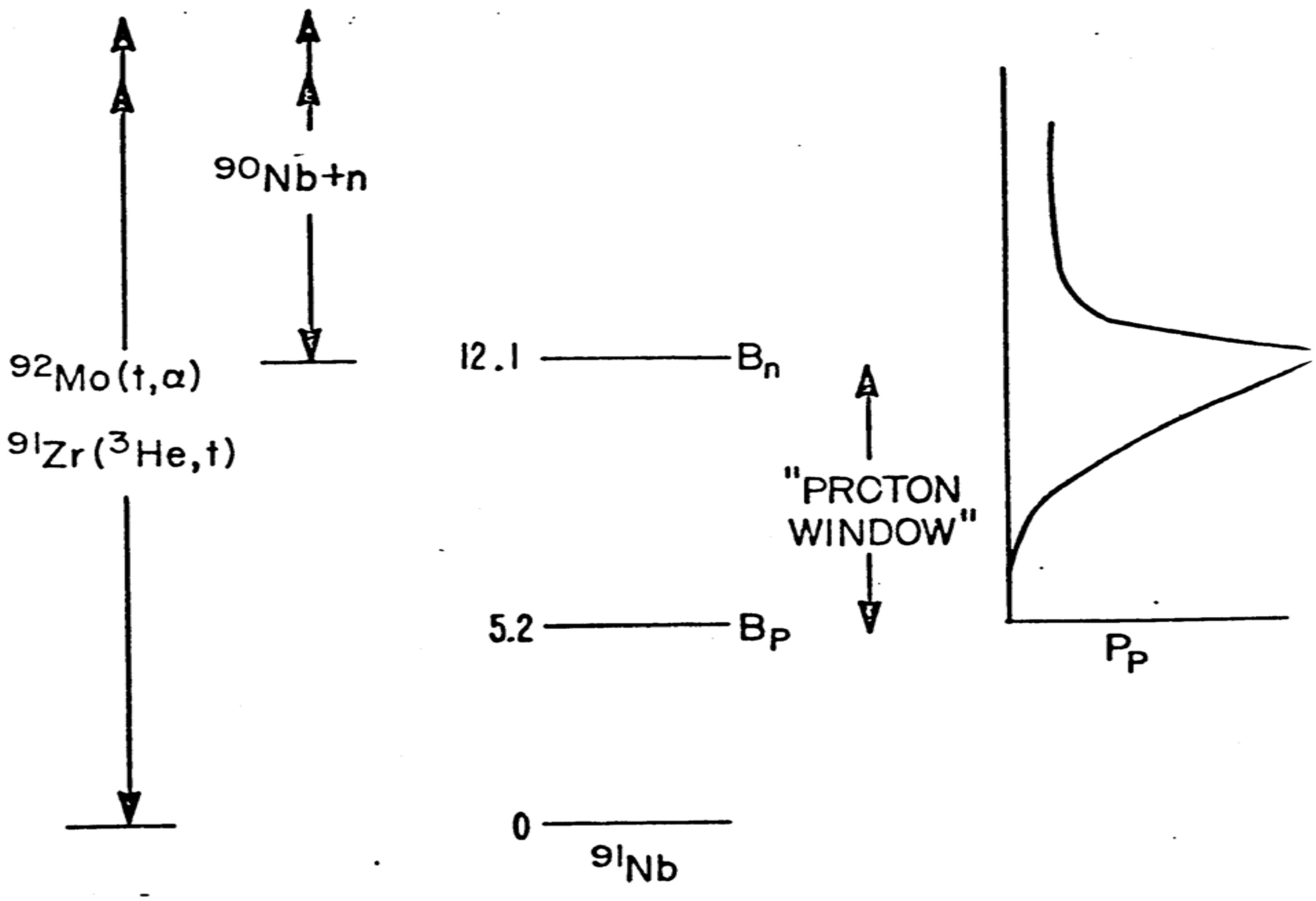
H. C. Britt and J. B. Wilhelmy

November 15, 1976

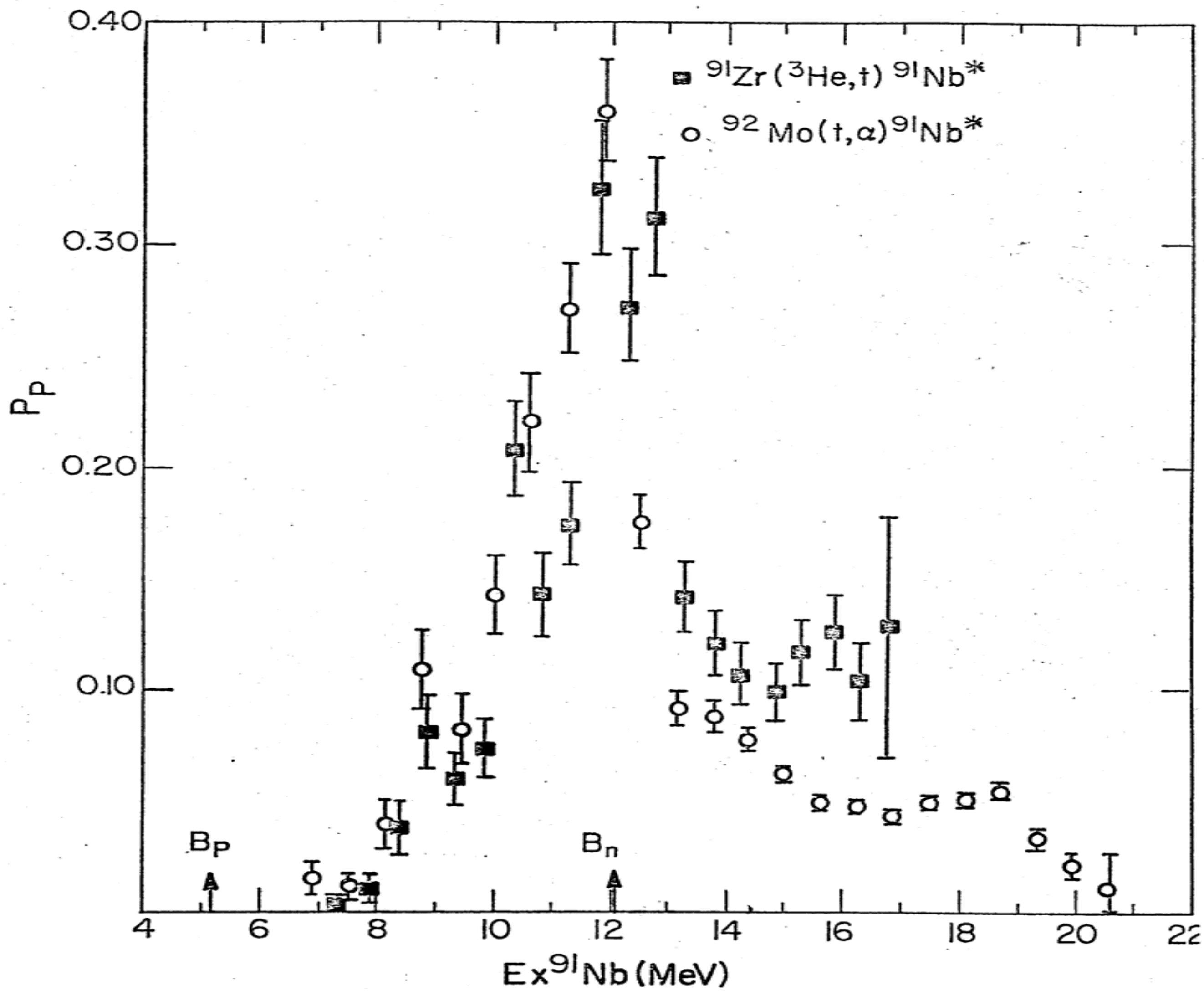
$^{91}Nb^*$


Mo92
14.84
σγ (.2μb+6E1mb), .8
91.906810
(t,α)
4− Nb90 8+
18.8 s
14.6 h
IT 2.2, e−
γ 122.9
β+ 1.500, ···, ε
γ 1129.2, 2319.0D, 141.2,···
E 6.111
(n,)
(1/−) Nb91 (9/+)
62 d
7E2 a
IT 104.5, e−
ε
γ 1205
E 1.253
(3He,t)
Zr91 5/+
11.22
σγ 1.2, 5.4
90.905643

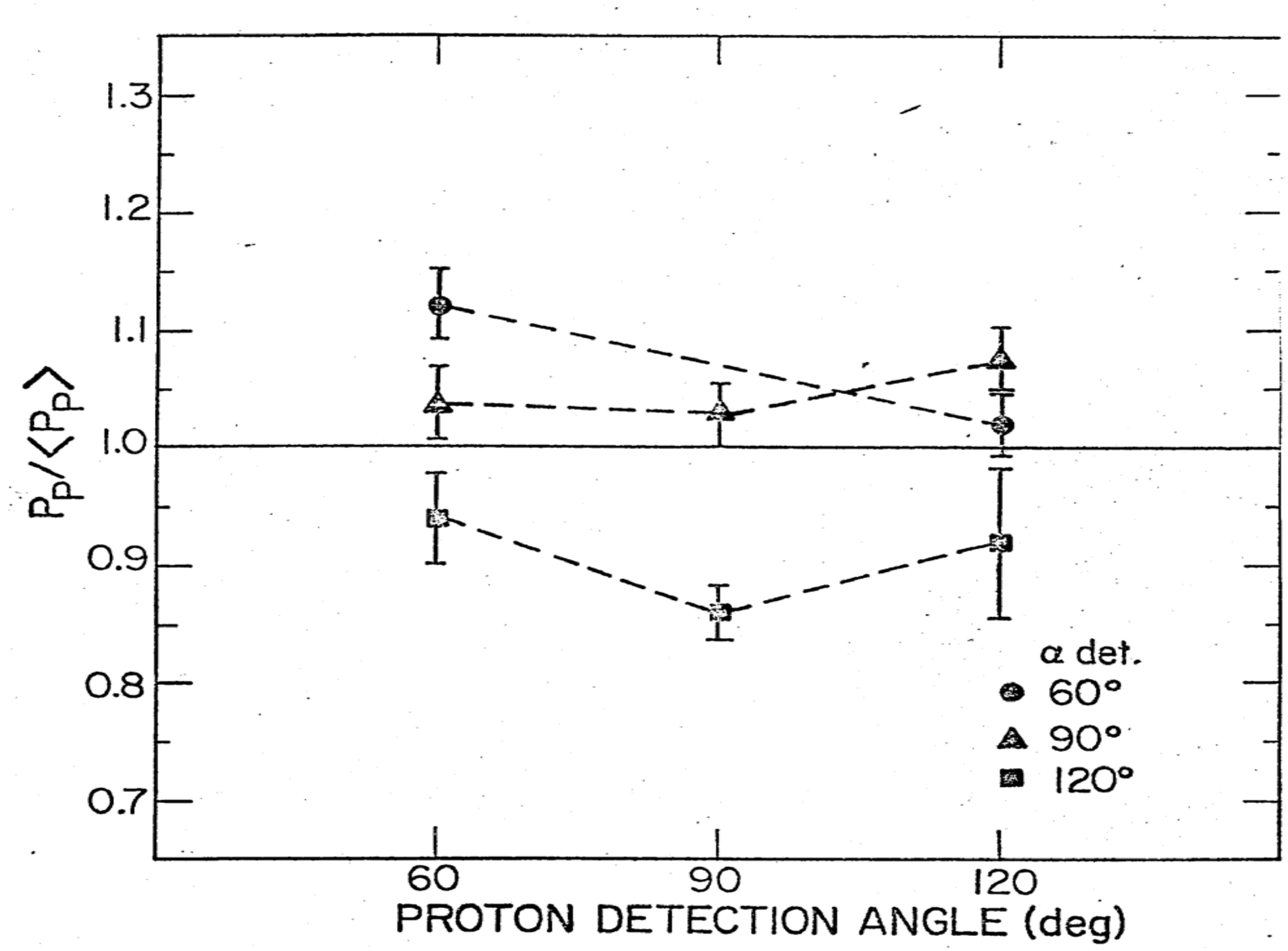
$^{91}Nb^{*}$ Energy Windows



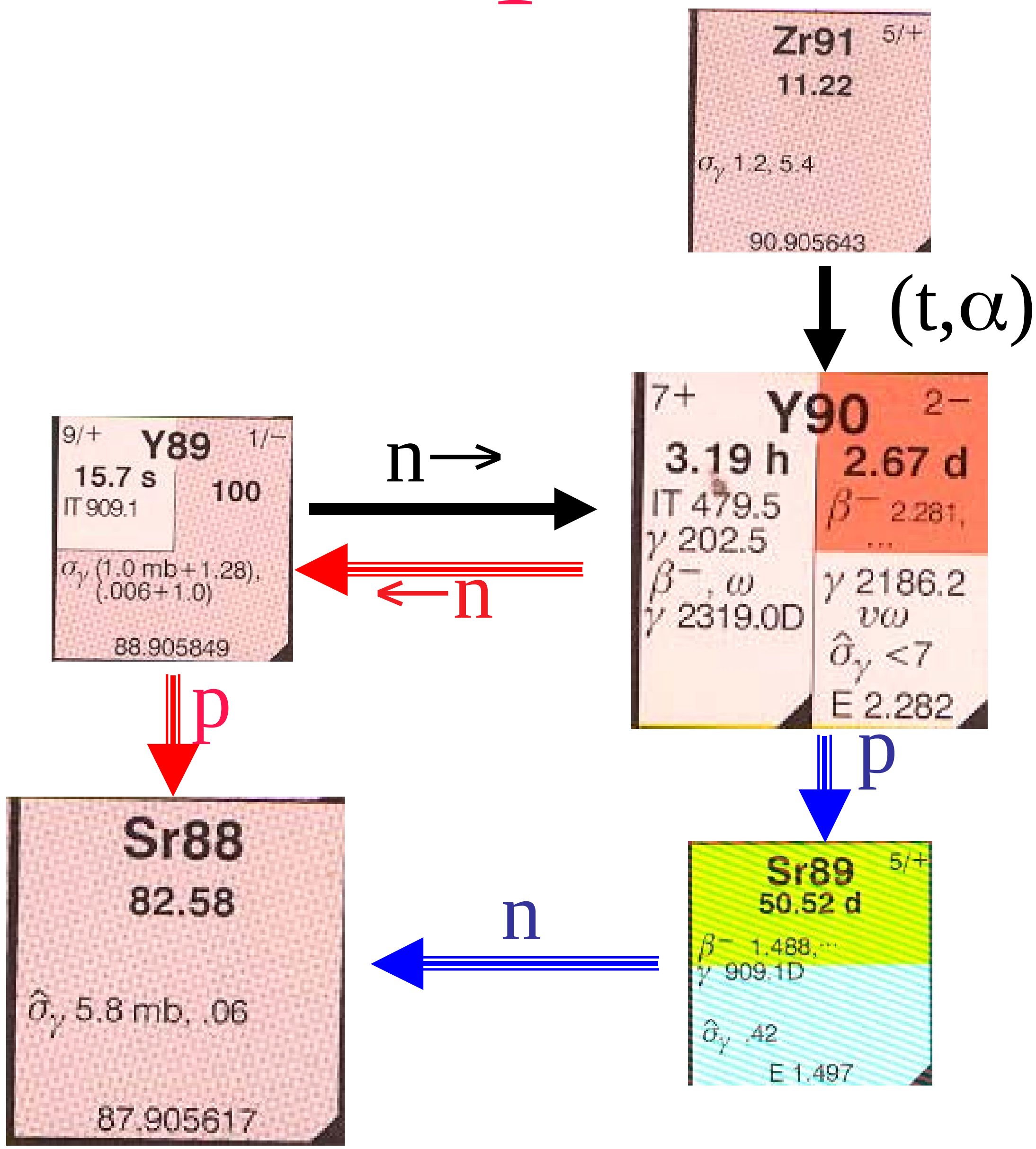
$^{91}Nb^* \rightarrow p$



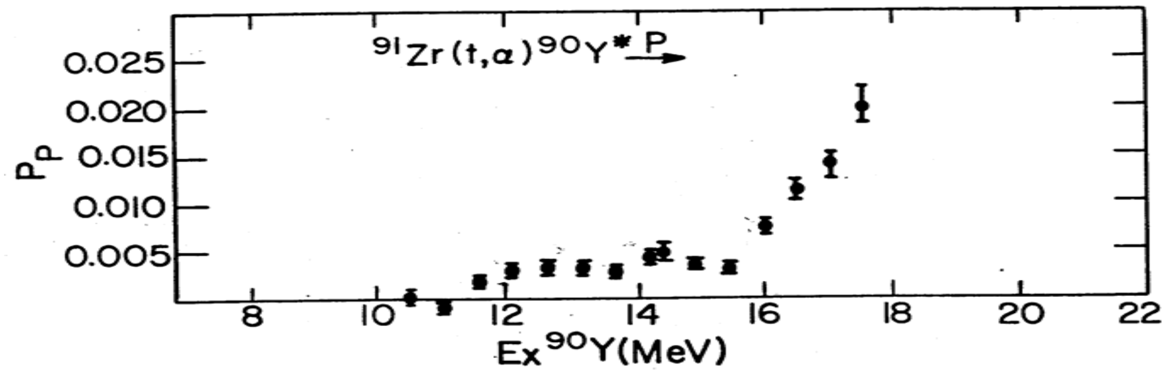
$^{92}Mo(t,\alpha)p$ Angular Dependence

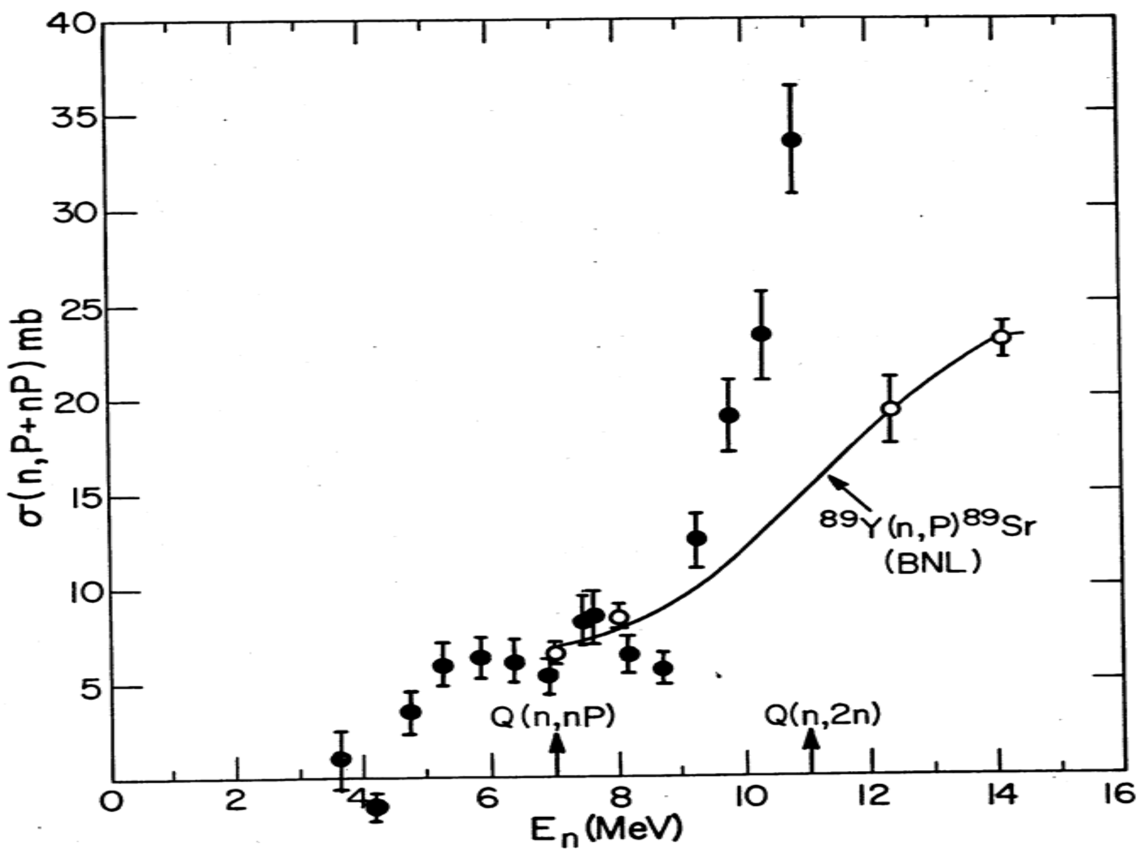


$^{90}Y*$


Zr91
5/+
11.22
σγ 1.2, 5.4
90.905643
(t,α)
Y89
9/+
1/−
15.7 s
IT 909.1
100
σγ (1.0 mb+1.28), (.006+1.0)
88.905849
n→
←n
Y90
7+
2−
3.19 h
IT 479.5
γ 202.5
β−, ω
γ 2319.0D
2.67 d
β− 2.281, ...
γ 2186.2
vω
σ̂γ <7
E 2.282
p
p
Sr88
82.58
σ̂γ 5.8 mb, .06
87.905617
n
Sr89
5/+
50.52 d
β− 1.488,...
γ 909.1D
σ̂γ .42
E 1.497

$^{91}Zr(t,\alpha)^{90}Y^{*} \rightarrow p$





Experiments

Don Barr
Sylvia Beatty
Jim Gilmore
Mac Fowler
Jere Knight
Rene Prestwood
Liz Trebor
Jerry Wilhelmy

Chip Britt
Ron Brown
Augustin Gouron

Darrell Drake
John Moses
Nelson Stein
Jules Sunier

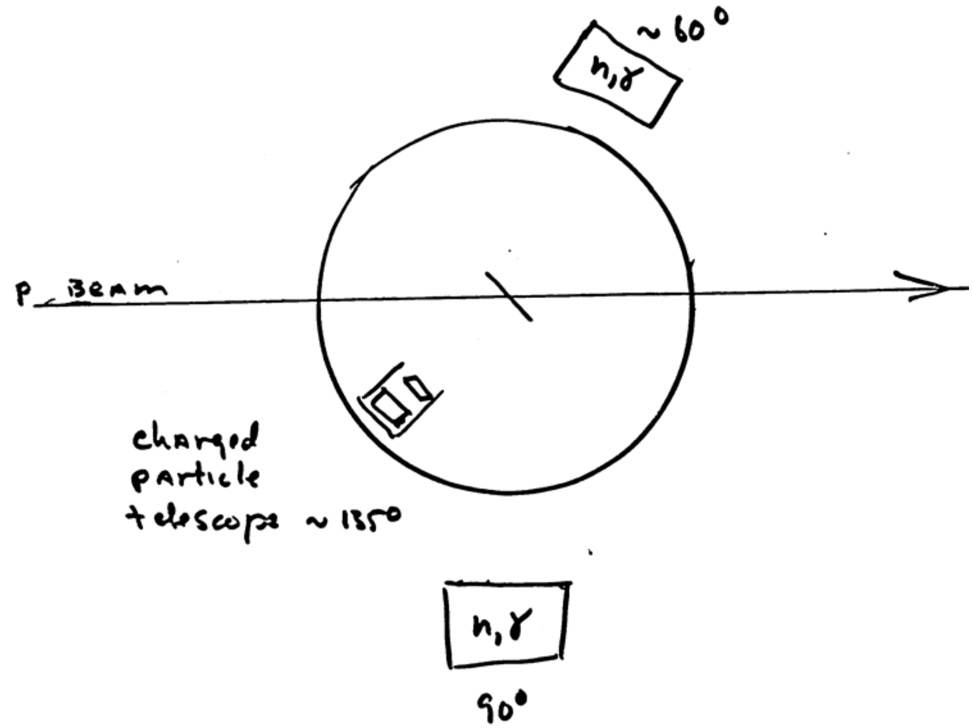
Calculations

Ed Arthur

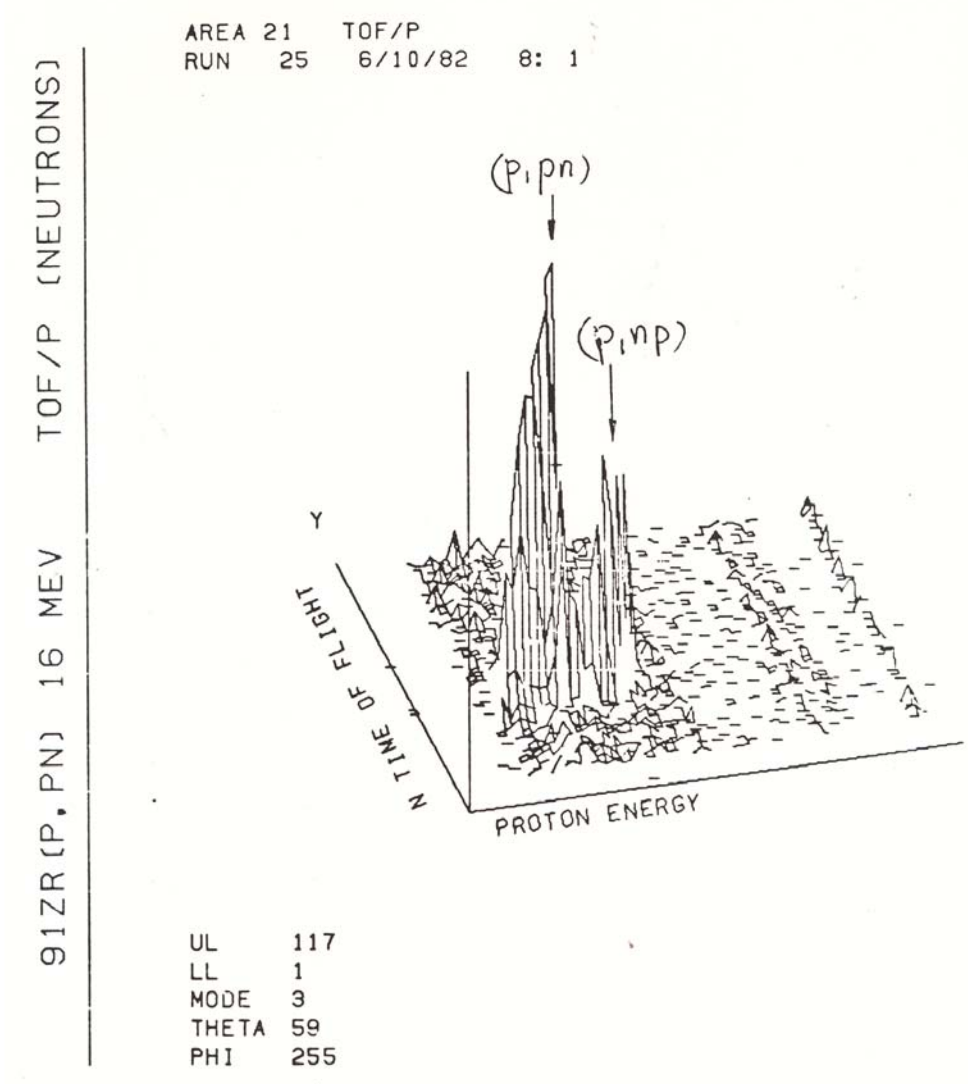
Exp. Setup for p+n Measurements

two independent neutron counters
in coincidence with ΔE-E telescope

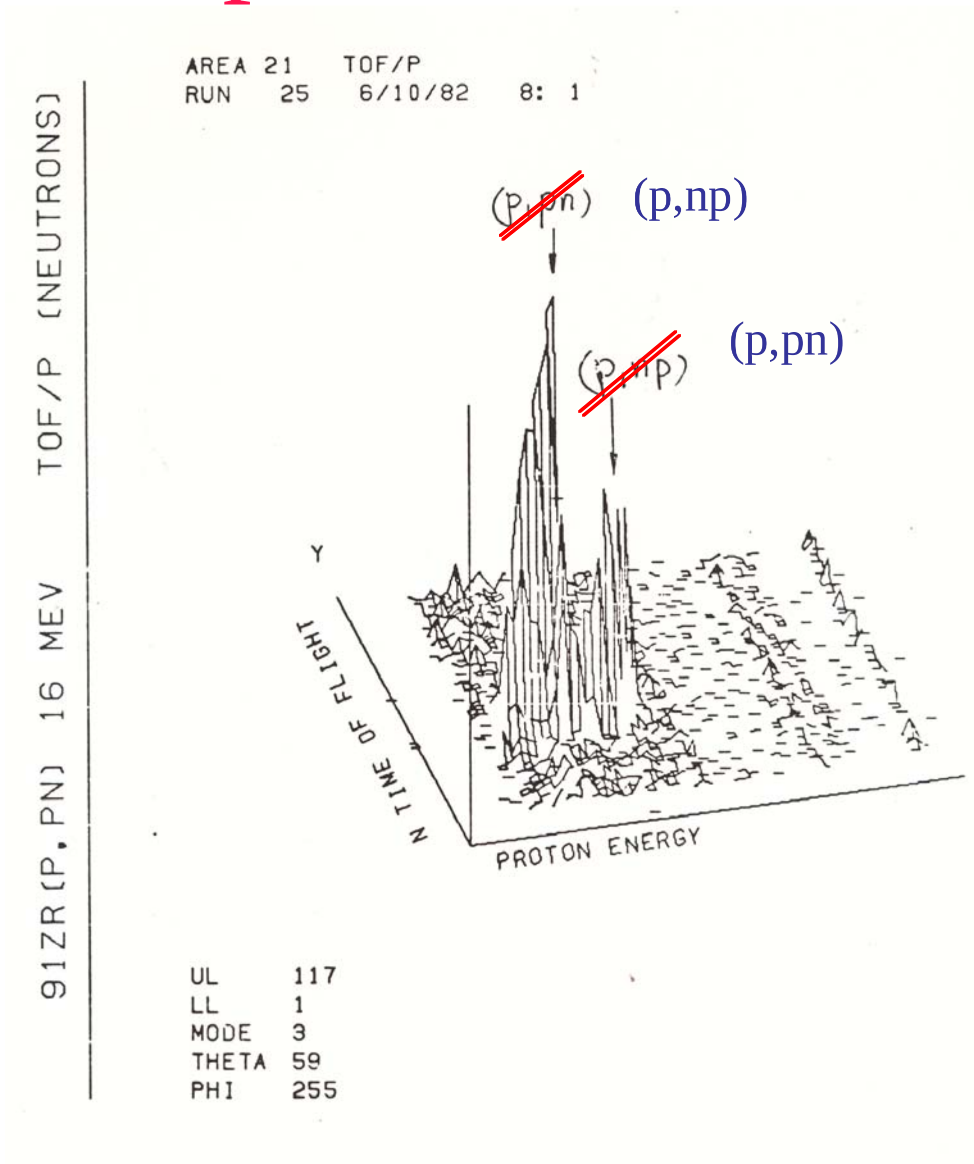
Los Alamos Tandem



$^{91}Zr+p \rightarrow {}^{92}Nb^{*} \rightarrow n+p$



$^{91}Zr + p \rightarrow {}^{92}Nb^* \rightarrow n + p$



“Future Plans” circa 1978

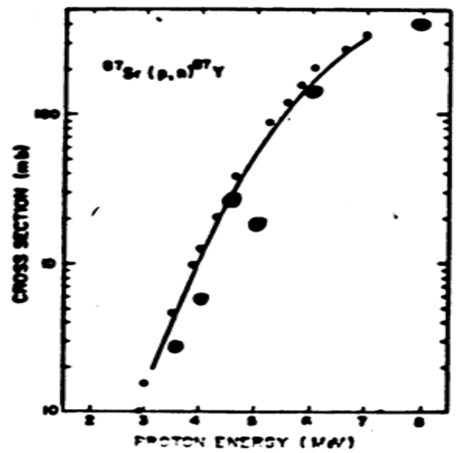
- FUTURE PLANS
  - RADIOACTIVE TARGET EXPERIMENTS

    1. 107D $^{88}Y(n,2n)^{87m,g}Y$ — $E_N = 14.1$ MEV
    2. 93D $^{168}Tm(n,2n)^{167}Tm$ — $E_N = 14.8$ MEV
    3. 93D $^{149}Eu(n,2n)^{148}Eu$ — $E_N = 14.8$ MEV

  - OTHER RELATED EXPERIMENTS FOR MODEL VERIFICATION

    4. SEPARATED ISOTOPE $^{144}Sm(n,2n)^{143}Sm$ — $E_N = 14.8$ MEV
       $(n,p)^{144}Pm$ — $E_N = 14.8$ MEV
    5. SEPARATED ISOTOPE $^{87}Sr(p,n)^{87}Y$ — $E_T = 2.7$ MEV
       $(p,2n)^{86}Y$ — $E_T = 14.65$ MEV
    6. SEPARATED ISOTOPE $^{88}Sr(p,n)^{88}Y$ — $E_T = 4.45$ MEV
       $(p,2n)^{87}Y$ — $E_T = 13.93$ MEV

EXISTING DATA FOR REACTION 5A.



Surrogates in the 21st Century

- Simple Reactions on Exotic Targets
  - Astrophysics
  - National Nuclear Security
  - Transmutation
- RIA
  - Inverse kinematics with radioactive beams
  - Gas targets (H,D,T,^{3}He,^{4}He,…)
  - “4π” detectors (charged particles, neutrons, gammas)

Physics Needs

- Modeling/Theory
  - Angular Momentum Modeling
  - Preequilibrium - Reaction Dependent
  - Breakup Effects (especially on D)
- Experimental
  - Inverse kinematics on few body targets
  - Develop counter arrays for RIA
  - Preequilibrium angular momentum effects